

## Mathematical Modelling of the Pulverised Coal Preparation for Combustion Using Plasma

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This paper studies the physics of pulverised coal preparation within a plasma burner (muffle). Compared with conventional coal burners, in this concept a proportion of the pulverised coal and air mixture is diverted from the main flow and heated by a low-temperature air plasma flame [1]. The plasma flame, as a heat source and oxidant, provides a high temperature radical-rich environment wherein complete volatiles evolution and partial gasification of the carbon residual takes place. This highly reactive fuel fraction, entering the combustion chamber of the furnace, mixes with and ignites the main stream of pulverised coal and air. The resulting flame does not require any additional heat source or any additional fuel to maintain the combustion stability.

The numerical simulation of coal preparation within the plasma burner was carried out using thermodynamic, kinetic and multi-dimensional computational fluid dynamics codes. The initial data for the numerical simulations were obtained from a full industrial-scale direct flow burner equipped with a plasma generator (100 kW of electric power). The experiments were carried out using 'Tugnuisky' bituminous coal (Table 1), at the Gusinozersk Thermal Power Plant (steam production of 640 t/h) in Eastern Siberia. A schematic view of the burner and the measured temperature profiles are shown in Figure 1. The coal and air mass flow rates through the muffle were 1750 kg/h and 3500 kg/h respectively, while the coal-air mixture inlet temperature was 350 K. The temperature radial profiles, taken at two locations along the burner length, show the propagation of combustion resulting from the plasma flame effect. At the first measurement location (curve 1), taken at 0.75 m from the plasma generator axis, a distinctive maximum at one side of the flow is revealed, while further downstream at the exit from the burner (curve 2) the profile has two maxima in the wall

layer. The maximum temperature along the burner reached 1300 K, indicating partial combustion of the volatile matter and partial gasification of the residual carbon.

Table 1. Chemical composition of ‘Tugnuisky’ bituminous coal (per a dry mass), mass %

C	O	H	N	S	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O+Na <sub>2</sub> O
61.7	13.2	4.1	1.2	0.39	11.6	4.42	1.97	1.18	0.37	0.30

The coal moisture content is 14%; ash content 19.4%; volatile matter 45% of combustible mass; and lower calorific value 23030 kJ/kg

The measured composition of the gas at the outlet of the muffle was as follows (volume %): CO=28.5; H<sub>2</sub>=8.0; CH<sub>4</sub>=1.5; CO<sub>2</sub>=2.0; N<sub>2</sub>=59.5; others = 0.5, including NO<sub>x</sub>=50 mg/nm<sup>3</sup>.

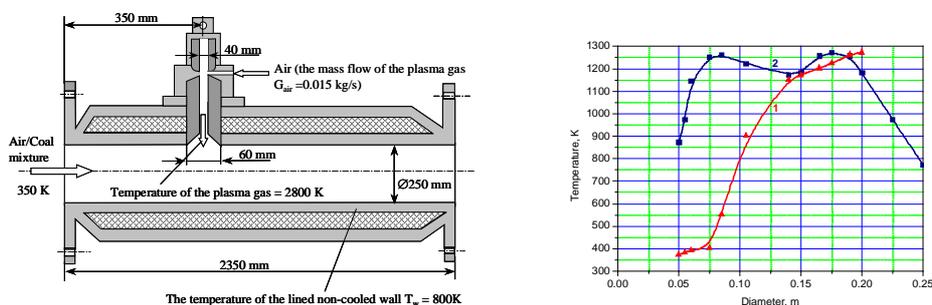


Figure 1. Diagram of the full-scale plasma chamber and measured temperature profiles inside the muffle (1 –0.75 m downstream of the plasmatron; 2 –outlet of the muffle)

The physics of the process were studied employing three mathematical models: zero and one-dimensional codes (Terra and Plasma-Coal) with an emphasis on thermodynamic equilibrium calculations and complex chemistry, and with a fully turbulent three-dimensional code (Fafnir) with an emphasis on the geometry and detailed volatiles combustion process. The thermodynamic code Terra calculates the species concentrations, specific power consumption and thermal physics coefficients (thermal conductivity, viscosity, heat capacity, etc.), of plasma activated pulverised coal preparation [2]. From the calculated species concentrations (Figure 2), in the temperature interval from 950 to 1250 K the concentration of combustible gases (CO+H<sub>2</sub>+CH<sub>4</sub>) varies from 36 to 51%. This range corresponds with the experimental data of 38%.

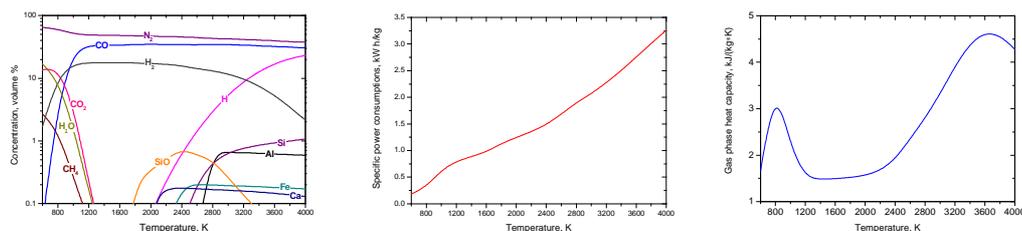


Figure 2. Species concentrations, specific power consumption and heat capacity versus temperature of plasma coal preparation for combustion (PCPC)

The 1-D kinetic code Plasma-Coal calculates the concentration of species, temperature levels and velocities of both gas and particulate phase along the muffler length. The plasma flame was taken into account in the equation for the conservation of energy. It is assumed to represent an internal source of heat with an empirically assigned distribution of heat-evolution along the axis. The model is distinguished by its detailed description of the kinetics of chemical reactions. The general scheme of 116 reactions includes the reactions of evolution of primary products from coal, and their further transformations within the gas phase. The initial chemical stage of coal conversion is the evolution of volatile matter (CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>, H<sub>2</sub>O, C<sub>6</sub>H<sub>6</sub>, C<sub>5</sub>H<sub>5</sub>N, C<sub>4</sub>H<sub>5</sub>N, CH<sub>3</sub>SH, C<sub>4</sub>H<sub>4</sub>S). After that there are two more stages: char carbon, nitrogen and sulphur gasification (7 reactions with H<sub>2</sub>O, CO<sub>2</sub>, CO, O<sub>2</sub>, NO, H<sub>2</sub>S), and conversion of evolved volatile products in the gas phase. A more detailed description of the code can be found in [3]. Figure 3 presents the dynamics of the PCPC process while Table 2 shows the numerical results at the muffler outlet (X=2.35 m).

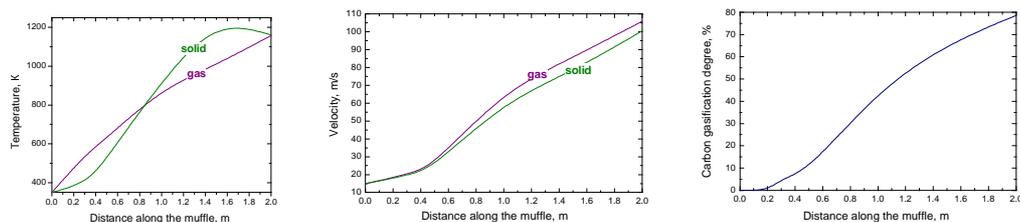


Figure 3. Profiles of temperature and velocity of the products and carbon gasification degree along the muffler

Table 2. 1-D calculations results of the coal plasma preparation for burning

CO	H <sub>2</sub>	CH <sub>4</sub>	CO <sub>2</sub>	H <sub>2</sub> O	N <sub>2</sub>	O <sub>2</sub>	NO	X <sub>C</sub>	V <sub>g</sub>	T <sub>g</sub>	t <sub>g</sub>
Volume %							mg/m <sup>3</sup>	%	m/s	K	s
29.27	15.25	0.44	2.25	1.18	50.23	0.85	5.5	78.7	106.1	1158.1	0.0126

Further study was effected using the Fafnir code to predict the thermo chemical preparation of coal. The code has been developed within the Imperial College Thermo-fluids group [4, 5]. Briefly, it is a 'CFD' code, which solves equations for mass, momentum and energy conservation. Further equations are solved for the mass fraction of volatiles, oxygen and products, and for the thermal radiation intensity. Physical models are employed for devolatilisation, volatiles combustion (fast non-premixed combustion), the char burnout and the turbulence (k-ε). The existing combustion model has been improved by introducing the 'laminar flamelets' concept into the calculations [6,7]. In this approach the single step reaction of volatiles combustion is replaced with the 'GRI-mechanism' kinematic scheme having around 280 reactions and 50 species included into the calculations [7]. The numerical

predictions of temperature radial profile and species concentrations at the exit of the plasma burner are presented in Figure 4. The predicted temperature profile shows some discrepancies at the symmetry line where a distinctive temperature minimum caused by the high velocity plasma flow is not well predicted.

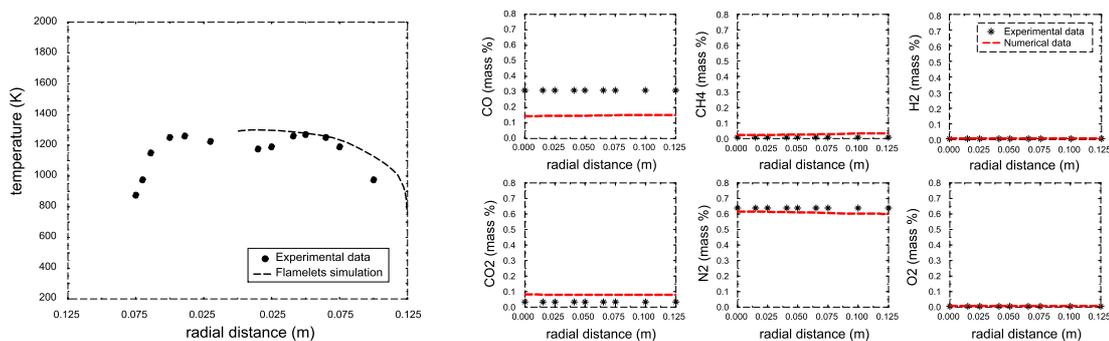


Figure 4. Predicted radial temperature profiles and species concentrations

For the species concentrations, higher differences between measured and predicted data are present for carbon monoxide concentration. The predicted zero oxygen concentration suggests completion of the coal preparation process, while the particles history analysis showed that about 57% of carbon has been gasified, whereas the experimental carbon burnout was 75%. This difference could be explained by the magneto-chemical properties of plasma flame, which will affect the chemical activation properties of pulverised coal. The effect of electric plasmas on solid fuels and the physics of their chemical decomposition are still not well understood.

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